SHALLOW WATER ACOUSTIC IMPULSE RESPONSE MEASUREMENT

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LONG-TERM GOALS

Goals for this project include: 1) the characterization of *ocean acoustic impulse response* (OAIR) in shallow water under various environmental conditions, 2) the development of predictive and synoptic methodologies/models linking acoustic communications system (modem) performance to environmental factors. Ultimately this information can be used to develop a robust acoustic modem design that can operate in the widest variety of environmental conditions or that can utilize a strategy of selectively moving to “best” locations to establish optimum point-to-point data communications. Based on the data acquired, a test-bed approach for improving undersea digital communications is expected.

OBJECTIVES

Global objectives for this program include the development and utilization of sensor technology in order to conduct measurements of channel impulse response for shallow water communications requirements. A mapping of the impulse responses/transfer functions variations for data communications and telemetry necessary to obtain accurate channel models. This will aid the development of efficient compensation techniques in order to design high-speed underwater acoustic modems for use aboard AUV's and other platforms. Measurements and modeling will be conducted to specify the impulse responses and their variations in terms of environmental parameters for the set of conditions available. Additional objectives include:

1) Shallow channel characterization/classification : *Doubly/Singly spread* (time and frequency) or *Overspread -- underspread* : to determine whether instantaneous or average measurements (in time under ergodicity assumptions or ensembles under stationarity assumptions). Noise Characterization: Rician, Rayleigh, or AWGN statistical behavior, 2) Estimation of channel time invariance, 3) Measurement of temporal variability vs. range in the frequency bands of interest, 4) Characterization of the channel for fading duration, outage, and co-channel independence. 5) Determination of channel coherence bandwidth for the propagation mode of interest through independent fading propagation path measurement. 6) Improved OAIR representations, 7) Development of path planning tools for maximizing communications coverage for AUVs. 8) Estimation of maximum channel capacity data transmission vs ISI, 9) Characterizing SNR per bit level. 10) Estimation of achievable coverage and cell sizes under an acoustic LAN cellular scenario (via co-channel interference measurements). 11) Establishment of guidelines with proposed specs/standards on certain design parameters for new, advanced modem development. 12) Development of methodology for specification of intricate coherent systems vs. simpler noncoherent systems. 13) Model development to aid in the performance assessment of existing and proposed modems/communications systems based upon measured and simulated associations with environmental effects.

APPROACH

The planned approach encompasses 1) a system level concept analysis and design, including error performance analysis for various hypothetical data communications architectures based on field IR

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measurements 2) development of an experimental setup design for procuring data and measurement of key parameters, 3) participation in offshore data collection, 4) conducting data evaluation, interpretation, and processing using techniques to increase SNR, and 5) providing a comparison between expected theoretical and experimental results providing justification of observed deviations.

Model development: channel

Matlab programs are being developed to post-process the output of acoustic propagation models for basic time and frequency data. Using this data, the programs are written to analyze the range-depth impulse response (IR) in the 2-dimensional space of a source at a stationary location. The motion of the receiver is simulated by selecting the IR along an arbitrary path in the space. Illustrative diagrams are produced from simulated data to: a) visually determine the path that a moving platform would follow to find a location of near optimum communications, b) estimate parameters (coherence time, coherence interval, framing, data rate) needed to maintain communications during motion, and c) provide a strategy that tailors communications requirements (data rate, framing) while a platform is stationary and while it is moving. Information derived from this approach will eventually be used to develop a testbed to assess communications system performance for different system architectures.

Model development: communication architecture

Both simulated and real data taken under difficult acoustical environmental conditions are used as input to communications models developed and written with MatLab. Several communications system architectures are being modeled, including single and multichannel structures using conventional linear adaptive equalizers as a baseline. Different adaptation schemes (LMS and RLS) are being investigated for convergence properties and residual error. A systems identification approach (SID) has been adopted and is being tested in comparison to the more conventional equalizers. This approach is well suited to system parameterization where it is desirable to establish a minimal set of model parameters to completely characterize the system. The choice is not unique, but such a characterization can provide a basis for establishing modem initial conditions, as well as providing a predictive scheme for estimating communications reliability.

Measurement

Acoustic signals representing data, impulses, continuous waves, or coded waveforms are devised to measure expected communications channel characteristics. In the simplest measurement procedure, these signals are broadcast from an acoustic transducer and received by a stationary set of hydrophones. The stationary array is configured for frequencies above 10 Khz and is deployed in shallow water (<100 fsw). The signal burst duration is adjusted to be long in comparison to the signal carrier period and environmental perturbation periods. Broadcast signals are repeated at periodic intervals and for periods as long as several hours. A receive array is used in either horizontal or vertical orientation to allow comunication parameters to be be studied as a function of propagation mode and beamformer azimuth, if so desired.

An alternate system is also being tested for use in this application. It relies on comparison of the broadcast signal in comparison to the received signal(s) and produces a direct measurement of the coherent time- and frequency- varying impulse response function by simultaneous real-time monioring of the broadcast and received signals.

Data Analysis

A feasible parameter distinction for multiple arriving paths can use observables such as: 1) *Field Intensities /Fluctuation statistics*, 2) *Phase*, 3) *Time Delays*, and 4) *Spreads in time/frequency domain*. The measurable quantities and their corresponding processed communications parameters; such as, *time* *arrivals, time duration, power, channel coherence bandwidth, field intensity, doppler spread factor, impulse response, ambient noise, reverberation, and interference.* Although a complete characterization is ideal and infeasible, our approach emphasizes measurement of as many observable parameters as possible.

Signal processing techniques will be applied to improve the quality of the measurements by suppressing various noise types and increasing the SNR of the data. The higher-order statistics (HOS) signal processing domain is more robust than the second order (autocorrelation, power spectrum) since it preserves the phase information, suppresses the AWGN, and detects and characterizes nonlinearities of a system (harmonic phase coupling etc.). Degraded impulse responses can be modeled as non-minimum phase systems with transfer functions having zeros inside and outside the unit circle. A variety of non-minimum phase system identification techniques based on higher-order statistics are available.

WORK COMPLETED

1) Matlab routines for visually observing IR response in 2-Dimensional range-depth space have been developed and are operational. The routines also allow selection of an arbitrary path, dividing that path into arbitrary intervals, and obtaining the IR associated with movement along the path.
2) Several communications models have been developed. These model simulations allow use of simulated or real impulse response data for decoding test data sequences, as well as assessment of BER and equalizer convergence properties. The System Identification (SID) model has been programmed and is operational.
3) A joint exercise using FAU developed acoustic data acquisition equipment with HBOI signals was completed in October, 1997. The exercise took place offshore Ft. Pierce, Florida over a period of three days with source and receive array fixed at an approximate 50' depth. Multiple sets of signals were used containing data, synchronization, and test waveforms. Data analysis has begun and data is currently being used to assess the performance of several simulated communications architectures.

RESULTS

<u>Communications Model</u>

Example results for the communications model development effort are given for the system shown in Figure 1. The acoustic channel is modeled using a system identification method. During training, the error signal e_k is mimimized through variation of the model parameters to approximate the actual channel response. Once adapted, a deconvolutional filter is used for decoding the data sequence. The illustrated model is a simple tapped delay line construct, however, more complex models are being developed using FDAF techniques.

The convergence properties and mean square error (MSE) for the SID model is illustrated in Figure 2. The SID approach provides less computational time to final MSE and allows a more straightforward DSP implementation when compared to more conventional methods such as RLS which relies upon matrix computation.

<u>Channel Model</u>

Sample results from the channel modelling effort have also been included here to illustrate significant time intervals of the most significant impulse response returns within a 2-D range-depth space. Figure 3 illustrates the output of this simulator for an environment having a maxiumum depth of 20 m, a maximum range of 0.4 km and known invariant surface and bottom conditions. The figure illustrates a series of IR with significant envelope widths from 2 ms (brown) to 18 ms (blue). The figure was prepared from a model using environmental conditions for an experiment conducted in shallow coastal waters near HBOI (Fort Pierce, FL). Additional work is being completed for comparison of the simulated IR with the experimental results, and to refine motion induced effects on IR.

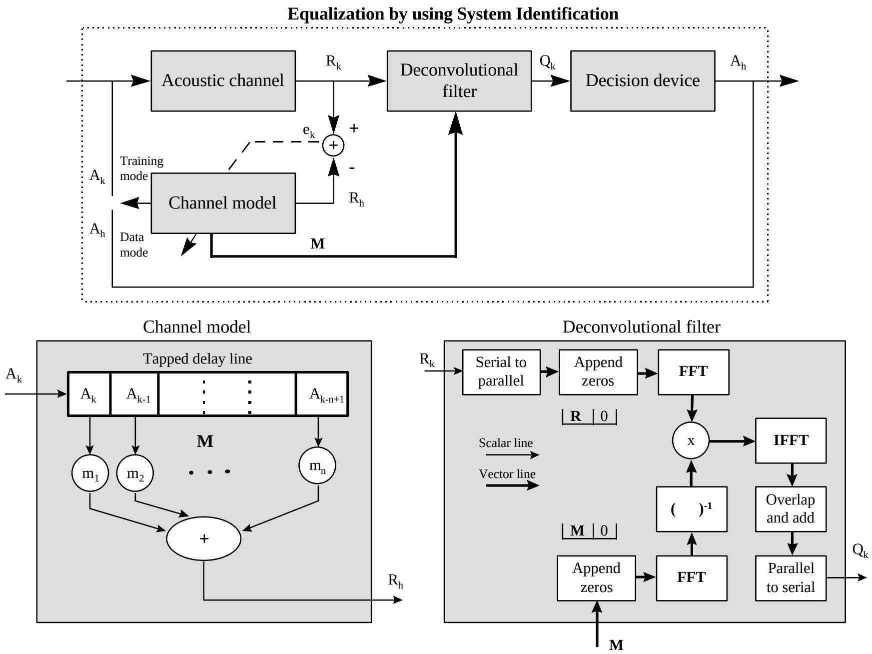

Figure 1: Illustration of preliminary SID communications system model and internal structure.

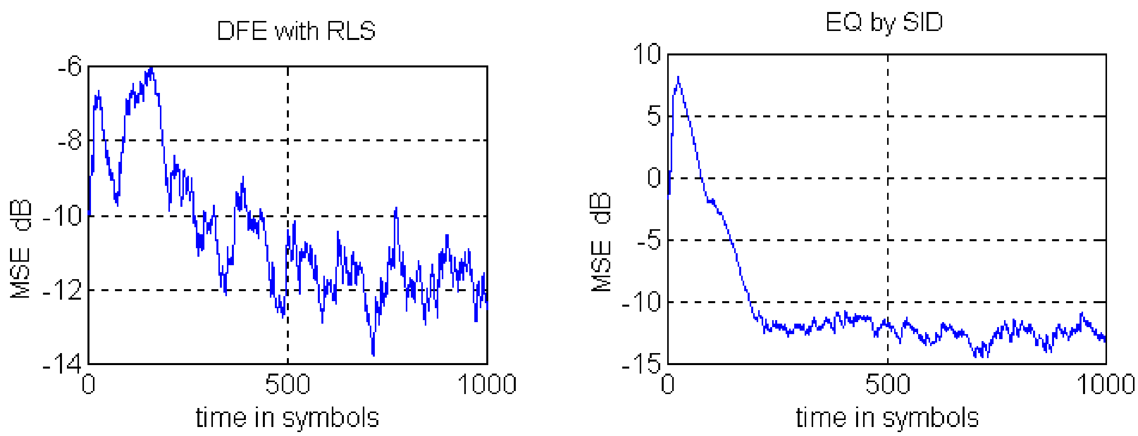

Fig. 2: Performance comparison of SID vs. Decision Feedback Equalizer for an RLS adaptation scheme.

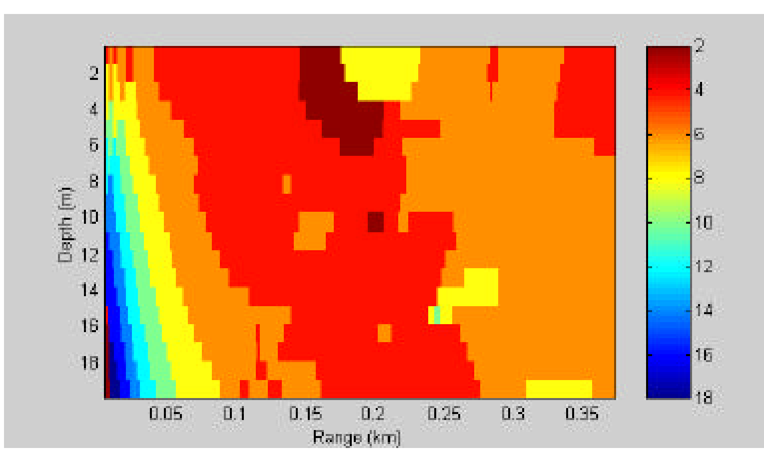

Figure 3: Range-Depth Space representing IR envelope width (ms) (colorbar scale): source:18m

IMPACT/APPLICATIONS

The channel simulator shows areas appropriate for acoustic communications in a 2-dimensional space. Often, acoustic communications performance reports are limited to studies of point-to-point communications without mention of how the two stationary points were selected. Results from this study will enable the determination of communication system performance based upon environmental factors. In the simplest case, the order of an acoustic modem's equalizer may be exceeded by the environmentally determined IR parameters. A robust acoustic communications system will require navigation by the acoustic platform into areas that allow optimum communications.

Applications to a strategy that incorporates movement include the use of roving AUVs and a central stationary node. The AUVs periodically communicate with the node from arbitrary locations within some predefined vicinity. This research suggests that a protocol is needed to allow the communications platform navigate based upon environmental information if communications is to be maintained.

Additional impacts include: operation and design based on knowledge of IR providing ability to predict BER and an initialization point for adaptive systems.

TRANSITIONS

An MMPE model used is the charge of Professor Kevin B Smith at the Monterey Naval Postgraduate School (NPS). A 3-Dimensional model is being developed. More refined models developed by NRL and others are expected to be incorporated into the simulation portion of this program. Experimental work was done in conjuction with FAU, Department of Ocean Engineering. Results will provide guidance for advanced hardware design.

RELATED PROJECTS

Nrad's "Telesonar" testbed; FAU's modem development, and WHOI's Utility Acoustic Modem development.

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